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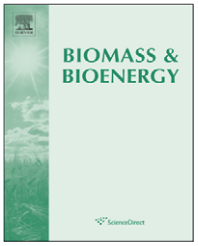

Concentration of key elements in North American meat & bone meal ☆

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ABSTRACT

Meat & bone meal (MBM) and related rendered protein commodities have potential for use in applications other than animal feed, including use as a fuel or a phosphorus fertilizer. In order to develop these applications, data on the elemental composition are required; the currently available elemental composition data have important limitations. To generate more appropriate and reliable data, MBM samples were collected from 17 North American rendering plants, carefully prepared and analyzed for 20 elements. Preliminary studies showed that the sample preparation process artificially increased levels of sulfur and nickel in a manner that was correctable. Concentrations of many elements were found to agree with previously published values, but concentrations of potassium, magnesium and copper were significantly different from the most authoritative reference. Concentrations of heavy metals tested for were low, and arsenic and cadmium were not detected in any sample. Among the elements tested, there were a number of pairs of elements whose concentration was correlated with high significance, which in some cases was due to the varying proportions of soft tissue and bone in the MBM. The data presented should allow the development of non-feed applications for MBM to proceed with increased confidence.

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1. Introduction

Meat & bone meal (MBM), and a family of closely related products including poultry by-product meal and meat meal, are secondary products resulting from the rendering of fat from unmarketable animal tissues. For decades, these materials have been used almost exclusively as high protein components of animal diets [1,2]. More recently, regulatory changes related to Europe's bovine spongiform encephalopathy (BSE) crisis and increased interest in the use of renewable resources have led to efforts to utilize MBM in non-nutritional applications [3]. Especially in the European Union, where MBM has been almost entirely excluded from its traditional feed markets, efforts to use MBM for its energy content or as a fertilizer are progressing rapidly. One hindrance to progress is a lack of appropriate data on the elemental composition of MBM. The data that are available suffer from several limitations—typically, only elements of nutritional interest are included [4,5], information on variability and typical ranges is lacking, and information necessary to evaluate the quality of the data is missing. While a few studies have reported on a wider variety of elements, these have involved samples from a single source [6,7].

The energy content of MBM has been utilized by combustion together with natural gas in traditional power plant boilers [8], in cement kilns [9,10], co-fired with coal in

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fluidized-bed furnaces [11,12], or transformed by pyrolysis into liquid and gaseous fuel [6,13]. Knowledge of the elemental composition of the MBM is important to these applications in a number of ways. The elemental composition of a fuel plays a role in determining the amount of regulated gasses, including NO_2, SO_2, CO and HCl, which will be produced when it is combusted [12]. The NO_x-eliminating catalysts used in coal-fired power plants are deactivated by catalyst poisons such as As, Na, K and P. The deactivation rate depends largely on the concentration of these catalyst poisons in the fuel [14,15]. Alkali metals and chlorine can create fouling deposits on heat exchanger or thermochemical conversion equipment surfaces or cause corrosion of metal parts [16–18].

Every fuel use of MBM generates non-combustible ash, which can equal 30% of the original mass of MBM [19]. No matter what is done with this ash, the elemental composition will be important. Whether the ash is landfilled, used as a substitute for sand in concrete [7] or used to sequester lead from water streams [20], the content of heavy metals that could leach into groundwater must be known [6,7].

MBM or MBM ash may be important as a future source of agricultural phosphorus. Rock phosphate, the only economically significant source of phosphorus for mainstream agriculture, is a non-renewable resource, the world production of which may have already peaked [21]. Additionally, rock phosphate and its derivatives have environmental drawbacks. Rock phosphate and its derivatives often contain heavy metals including cadmium, lead, copper, arsenic, nickel, chromium and zinc [22–24]. Use of rock phosphate-derived fertilizer over many years can result in a build-up of metals, especially cadmium, in agricultural soils and contamination of food crops [25–27]. Although the use of MBM or MBM ash as a phosphorus fertilizer has its own technical difficulties [21,28,29], it may become an increasingly attractive alternative if it is shown to pose less heavy metal risk, in addition to being renewable.

The present study is intended to provide data on the elemental composition that will aid in the development of the applications described above and to produce values that are more general and more reliable than those previously available.

2. Materials and methods

2.1. MBM samples and questionnaires

MBM samples were obtained by the Fats and Proteins Research Foundation (Alexandria, VA) from 17 rendering plants in the United States and Canada, and provided to the researchers without revealing the identity of the manufacturer, as described previously [30]. The anonymous manufacturers provided detailed information on their raw material and processing method.

2.2. Sample preparation

Individual MBM particles vary widely in size and composition, and the particles have a strong tendency to spontaneously segregate, so care was required to obtain small, representative samples for analysis. Samples of MBM were thoroughly homogenized and split into sub-samples by repeatedly passing through a riffle box, and then cone-and-quartering. Sub-samples were processed in a cryogenic mill (model 6800, Spex Centiprep Inc., Metuchen, NJ), using a stainless steel impactor, to the point where at least 95% of the sample would pass through a wire mesh sieve with 710 μm openings.

2.3. Elemental analysis

Following the procedures described by Dierenfeld et al. [31] and in AOAC official method 985.01 [32], dry samples were digested in a microwave digestion unit (MARS Xpress, CEM Corp, Matthews, NC). They were then analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES). As, Cd, Co, Pb, Mo, Ni and Zn were analyzed using an Ultima ICP (Horiba Jobin-Yvon Inc., Edison, NJ). Al, B, Ca, Cu, Fe, Mg, Mn, N, K, P, Na and S were analyzed using an Optima 5300 DV ICP (Perkin-Elmer, Waltham, MA). Cl was measured using a chloride analyzer (Model 926, Corning, Inc., Corning, NY). Samples from each source were analyzed for each element in duplicate, except for the elements Ni, As, Cd, Co, Pb and Mo for which only single analyses were conducted due to sample size constraints.

2.4. Bone content analysis

The mass percentage of bone particles in each sample was determined in quadruplicate using a heavy-fluid method adapted from Mendez and Dale [33]. Approximately 4 g dry, defatted MBM and 80 mL chloroform were added to a graduated cylinder and stirred to break apart any multi-particle clumps. This suspension was allowed to settle for 5 min, during which a large majority of the soft tissue particles floated to the surface and the bone particles sank to the bottom. The top layer of particles and the liquid were then filtered through Whatman #50 filter paper in a Büchner funnel, leaving behind undecanted bone particles. Both fractions of the MBM were dried and weighed to determine the proportions of bone and soft tissue particles.

2.5. Statistical analysis

Statistical analysis was performed using SAS v.8 (SAS Institute Inc., Cary, NC) and Microsoft Excel xp (Microsoft Corporation, Redmond, WA). Propagation of error formulas was applied when appropriate to correctly estimate error.

3. Results and discussion

3.1. Contamination due to milling medium

Although milling the MBM samples into a fine powder was useful for producing small, representative analytical samples, there is always the concern that the milling medium will contaminate the sample and bias the analyses. To address this potential source of error, samples of a single type of MBM were milled for lengths of time both longer and shorter than

the standard 6 min used in all other experiments (Fig. 1). Of the elements quantified in the present work, the mill manufacturer reported that iron, sulfur, manganese and nickel could be present in the milling medium. The results show that concentrations of sulfur and nickel increased significantly ($\alpha = 0.05$) as a function of milling duration; the trends for iron and manganese were insignificant. Corrections to reported concentrations of sulfur and nickel were made by assuming that the rate of increase in concentration would be the same for all samples, and using the regression equations to estimate the proportions of the measured concentrations that were artifacts of the milling and subtracting. Specifically, the values in the following sections have been adjusted downward by 375 ppm for sulfur and 231 ppb for nickel.

3.2. *Elemental composition*

The concentrations of many of the elements determined in this study are in relatively good agreement with previously published values (Table 1). The values reported by the National Research Council [4] for the elements K, Mg and Cu, however, fall completely outside of the range of concentrations found in all 17 samples tested in the present study. It is possible that this disagreement is due to inadequate sample size or flawed methodology used in the previous report, but this cannot be evaluated because the report does not reveal the source of the data or experimental details. Our findings for these elements are in better agreement with a recent report by Chaala and Roy [6]. The elements aluminum and boron displayed the greatest variability in proportion to their mean in our data. This result may be an artifact of our methodology; when each element was determined four times in a single sample, the values for aluminum and boron had the greatest standard deviations as a percentage of their means.

The official definitions of MBM, meat meal and poultry by-product meal all state that "the Calcium (Ca) level shall not be more than 2.2 times the actual Phosphorus level" [34]. Among the samples we examined, 5 of the 17 samples exceeded this Ca:P ratio limit, but the difference was not statistically significant ($\alpha = 0.05$).

The concentrations of many trace elements were very low. Arsenic and cadmium were not detected in any sample. Molybdenum was not detected above 1 ppm in any sample and cobalt was not detected above 445 ppb.

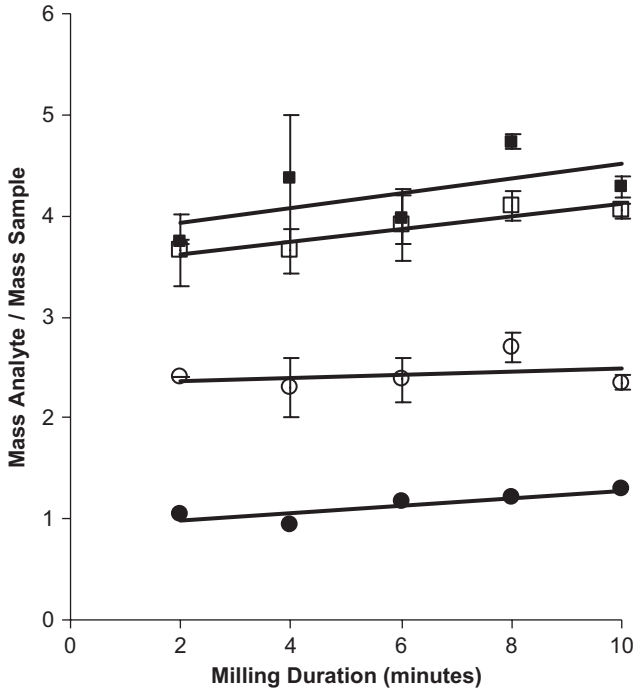

Fig. 1 – Contribution of milling medium to measured concentrations of iron $\times 10^4$ (■), sulfur $\times 10^3$ (□), manganese $\times 10^5$ (○) and nickel $\times 10^6$ (●) as a function of milling duration. Each data point is the average of two analyses, except nickel data points, for which there was only one analysis. Error bars represent ± 1 standard deviation; solid lines are best-fit linear regression lines.

3.3. *Correlations*

Among the elements tested, there were a number of pairs of elements whose concentration was correlated with high significance ($\alpha = 0.01$, Table 2). For the most part, the concentrations of the macrominerals (concentration >1000 ppm) were not correlated to trace minerals; the exceptions were the pairs Mg, Mn and Na, B. The correlations between many of the macrominerals are a consequence of the trade-off between bone and soft tissue in MBM. The majorities of Ca and P in a higher animal are in the bones, in a fixed ratio; the majorities of the nitrogen and sulfur exist in protein, which is concentrated in the soft tissue. The concentrations of N, Ca, P, S and K were correlated with high significance ($\alpha = 0.01$) to the mass percentage of bone in an MBM sample (Table 3). The content of these elements could be controlled to some extent either by varying the bone to offal ratio input to the rendering process or by a post-rendering fractionation of MBM, such as that described by Garcia et al. [35]. The explanation for the positive correlation between many pairs of trace minerals is not obvious—perhaps each is a roughly equivalent indicator of the quality of food or atmosphere the animals were exposed to during their lives, or the environment to which the material was exposed to during some stage of processing.

Little correlation was found between the elemental composition of MBM and either the species it was made from or the rendering parameters (see Electronic Annex A in the online version of this article). An exception was that the only three samples that had undetectable levels of arsenic, cadmium, cobalt, lead and molybdenum were also the only three samples made from 100% swine tissue—this may be a coincidence.

4. Conclusions

The availability of more complete and reliable data on MBM mineral composition should allow the development of

Table 1 – Elemental composition of MBM from 17 manufacturers on a dry basis

	Lower detection limit	Minimum	Mean ± 1 standard deviation	Maximum	Previously published values	
					Meat with bone, meal rendered, 93% DM[a]	MBM from Quebec, Canada[b]
Ca (%)	10^{-6}	6.15	9.42 ± 1.12	14.8	10.3	6.72
N (%)	10^{-6}	6.82	8.44 ± 0.16	9.56	8.06	–
P (%)	10^{-6}	3.03	4.40 ± 0.52	6.61	5.10	3.18
Na (%)	10^{-6}	0.580	1.03 ± 0.103	1.78	0.72	0.872
Cl (%)	10^{-6}	0.390	0.83 ± 0.00	1.75	0.74	–
K (%)	10^{-6}	0.315	0.557 ± 0.121	0.895	1.33	0.634
S (%)	10^{-6}	0.218	0.380 ± 0.093	0.473	0.25	–
Mg (%)	10^{-6}	0.175	0.252 ± 0.041	0.590	1.02	0.160
Fe (ppm)	1.0	266	618 ± 139	1051	684.0	560.5
Al (ppm)	1.0	53.0	235 ± 217	594	–	< dl
Zn (ppm)	0.5	73.8	93.6 ± 29.3	128	89.0	99.8
Mn (ppm)	1.0	5.50	16.5 ± 5.40	34.0	13.0	35.2
Cu (ppm)	1.0	7.00	14.5 ± 5.04	26.5	2.0	22.0
B (ppm)	1.0	1.00	9.96 ± 22.7	30.5	–	–
Cr (ppm)	–	–	–	–	–	5.9
Ti (ppm)	–	–	–	–	–	3.5
Ni (ppm)	0.1	0.96	3.00 ± 1.62	7.79	–	2.9
Pb (ppm)	0.3	< dl	1.19[c]	36.2	–	< dl
I (ppm)	–	–	–	–	1.31	–
Mo (ppm)	0.1	< dl	0.44[c]	1.00	–	< dl
Co (ppm)	0.07	< dl	0[c]	0.445	0.18	0.4
Se (ppm)	–	–	–	–	0.26	< dl
As (ppm)	0.3	< dl	< dl	< dl	–	< dl
Cd (ppm)	0.07	< dl	< dl	< dl	–	< dl
V (ppm)	–	–	–	–	–	< dl

"< dl" indicates that an element's concentration was below the limit of detection for the method used.
[a] [4].
[b] [6].
[c] Indicates cases where the median is reported rather than the mean, due to some samples in the set having concentrations below the detection limit; for this purpose, data points below the limit of detection were treated as zero.

Table 2 – Pairs of elements whose concentrations correlate with high significance ($\alpha = 0.01$, $n = 17$)

Elements	r	Elements	r
Ca, N	−0.89	S, Mg	−0.63
Ca, P	0.98	Mg, Mn	0.64
Ca, K	−0.73	Na, B	0.63
Ca, S	−0.90	Fe, Al	0.71
N, P	−0.87	Fe, Co	0.63
N, S	0.94	Fe, Mo	0.61
N, Mg	−0.70	Al, Mo	0.74
P, K	−0.73	Zn, Cu	0.68
P, S	−0.86	Mn, Cu	0.69
Cl, Na	0.98	Co, Mo	0.69

'r' is the Pearson correlation coefficient.

Table 3 – Elements the concentrations of which correlate to MBM bone content with high significance ($\alpha = 0.01$, $n = 17$)

Element	r
Ca	0.95
P	0.94
N	−0.88
K	−0.69
S	−0.87

'r' is the Pearson correlation coefficient.

alternative applications to proceed with increased confidence. Data on the range of chloride concentration, for example, will assist engineers in making appropriate choices in designing an MBM-utilizing power plant. The low levels of heavy metals discovered in the samples tested will help regulatory bodies determine how MBM and MBM ash may be used in environmental applications. The instances of contradiction between our results and those of the National Research Council [4] may suggest that a re-examination of the older data is in order.

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Appendix A. Supporting Information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biombioe.2007.12.011.

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